AIRCRAFT INTERIOR NOISE REDUCTION BY ALTERNATE RESONANCE TUNING

ONE YEAR PROGRESS REPORT

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Prepared by: James A. Gottwald
Donald B. Bliss

Department of Mechanical Engineering
and Materials Science
Duke University
Durham, North Carolina 27706

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SECTION 1. INTRODUCTION

Existing interior noise reduction techniques for aircraft fuselages perform reasonably well at higher frequencies, but are inadequate at lower frequencies, particularly with respect to the low blade passage harmonics with high forcing levels found in propeller aircraft. A method is being studied which considers aircraft fuselages lined with panels alternately tuned to frequencies above and below the frequency that must be attenuated. Adjacent panels would oscillate at equal amplitude, to give equal source strength, but with opposite phase. Provided these adjacent panels are acoustically compact, the resulting cancellation causes the interior acoustic modes to become cutoff, and therefore be non-propagating and evanescent. This interior noise reduction method, called *Alternate Resonance Tuning* (ART), is currently being investigated both theoretically and experimentally. This new concept has potential application to reducing interior noise due to the propellers in advanced turboprop aircraft as well as for existing aircraft configurations.

The ART technique is a procedure intended to reduce low frequency noise within an aircraft fuselage. A fuselage wall could be constructed of, or lined with, a series of special panels which would allow the designer to control the wavenumber spectrum of the wall motion, thus controlling the interior sound field. By judicious tuning of the structural response of individual panels, wavelengths in the fuselage wall can be reduced to the order of the panel size, thus causing low frequency interior acoustic modes to be cutoff provided these panels are sufficiently small. By cutting off the acoustic modes in this manner, a significant reduction of interior noise at the propeller blade passage harmonics should be achieved.

Current noise control treatments have already demonstrated that the mass and stiffness of individual fuselage panels can be altered. It seems reasonable, therefore, that panel resonant frequencies can be manipulated to achieve the ART effect. Application of this concept might involve the modification of existing structural panels or development of a new design for fuselage interior trim panels. Although complete acoustic cutoff will not be achievable in practice, an approximate cancellation should still substantially reduce the interior noise levels at the particular frequency of interest. It is important to note that the ART method utilizes the flexibility and dynamic behavior of the structure to good advantage, although these properties are not normally beneficial in noise control.

This progress report summarizes the work carried out at Duke University during the second six months of a contract supported by the Structural Acoustics Branch at NASA Langley. Considerable progress has been made both theoretically and experimentally as described in the following sections. It is important to note that all of the work carried out so far indicates the ART concept is indeed capable of achieving a significant reduction in the sound transmission through flexible walls.

SECTION 2. THEORETICAL ANALYSIS

Model problem development and analysis continues with the Alternate Resonance Tuning concept. Various topics are presently at different stages of completion and will be described below. These topics include optimization of panel mass ratios, panel computer code verification and agreement with experimental data, and flexible frame modeling.

Section 2a. Mass Ratio Optimization

A mid-year progress report presented the basic theoretical model which is currently being developed. This model involves sound transmission through a wall of panels of infinite and periodic extent composed of spring-mass-damper elements in various patterns.[1] Figure 1a shows a typical result of this model. Note that the design frequencies for this four panel transmission loss calculation are varying slightly from the desired ART frequencies of 1, 2, and 3 (in nondimensional frequency). This is due to the presence of a small but finite amount of damping in the panel system, as well as apparent mass due to the loading of the surrounding fluid . The basic panel mass ratios (used to calculate the results shown in Figure 1a) for this four panel system without damping and apparent mass were initially derived analytically using MACSYMA, a large symbolic manipulation program. These mass ratios were obtained for a given case with certain assumed values for the various nondimensional parameters included in the modeling. Initial attempts to find the analytic expressions for these mass ratios for the general case (including damping and apparent mass) proved unsuccessful due to additional complexity in the governing system equations, and accordingly a numerical routine was developed which solved the governing equations for a ratio of transmitted to incident pressure (which is then converted to a transmission loss in decibels). A variation in the panel computer code has been added which optimizes the mass ratios among the panel elements to produce a maximum ART effect at any desired frequencies. This allows the design attenuation to be set at precise frequencies and, as such, the lower harmonics of the desired frequency are now precisely located. This additional effect is achieved using a Newton-Raphson scheme in multiple dimensions, with appropriate convergence criteria. A typical result is shown in Figure 1b.

Section 2b   Derivation of Experimental Panel Dynamic Parameters

Work is in progress in an effort to correlate data taken during the early part of the ART program. A key element in the correlation effort is modeling of the experimental duct
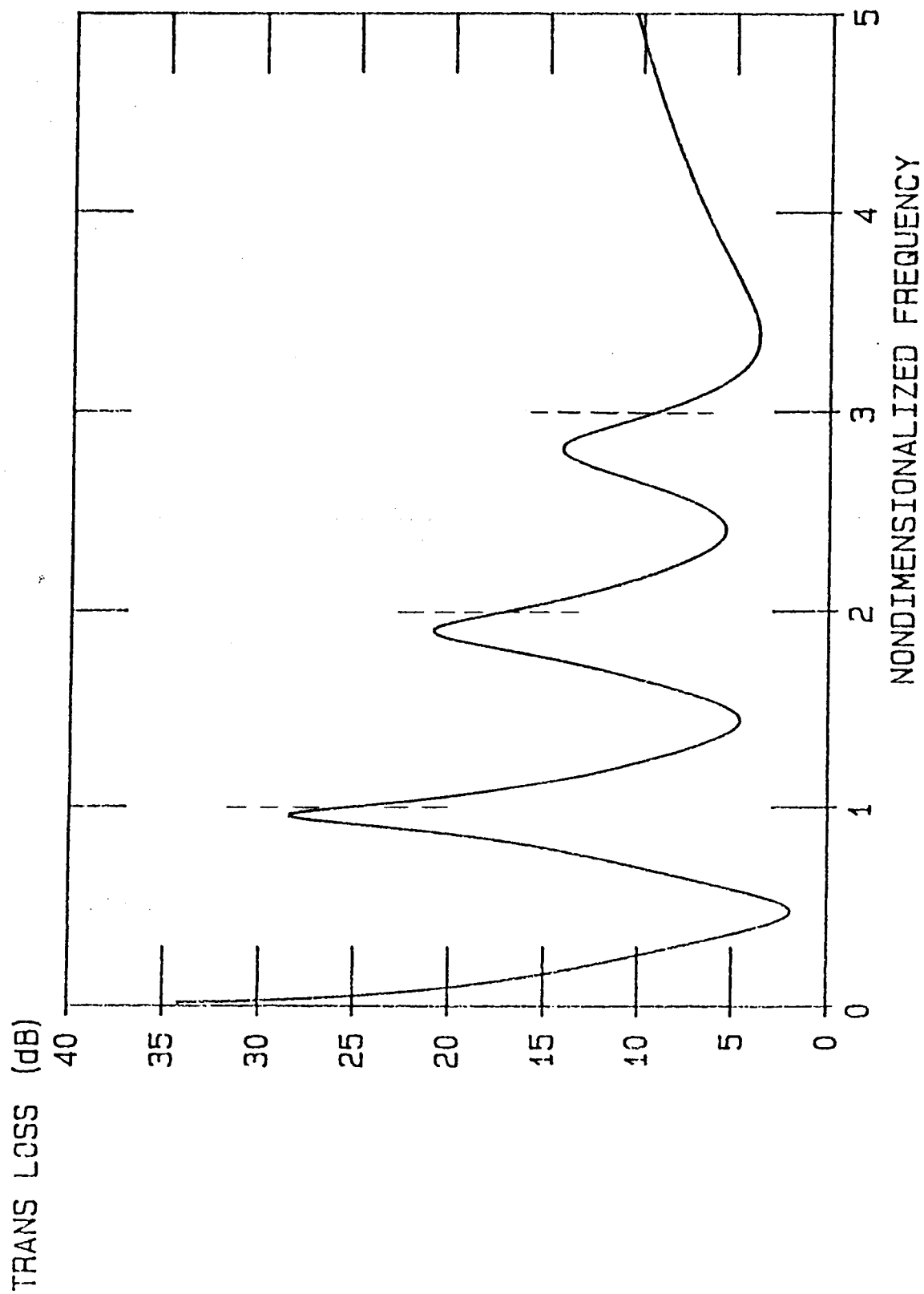
TRANS LOSS (dB)

Figure 1a: Typical four panel model result showing three ART attenuation frequencies. Panel damping set to zeta = 0.05. Note that ART peak attenuation frequencies are slightly shifted from nondimensional frequencies of 1, 2, and 3.
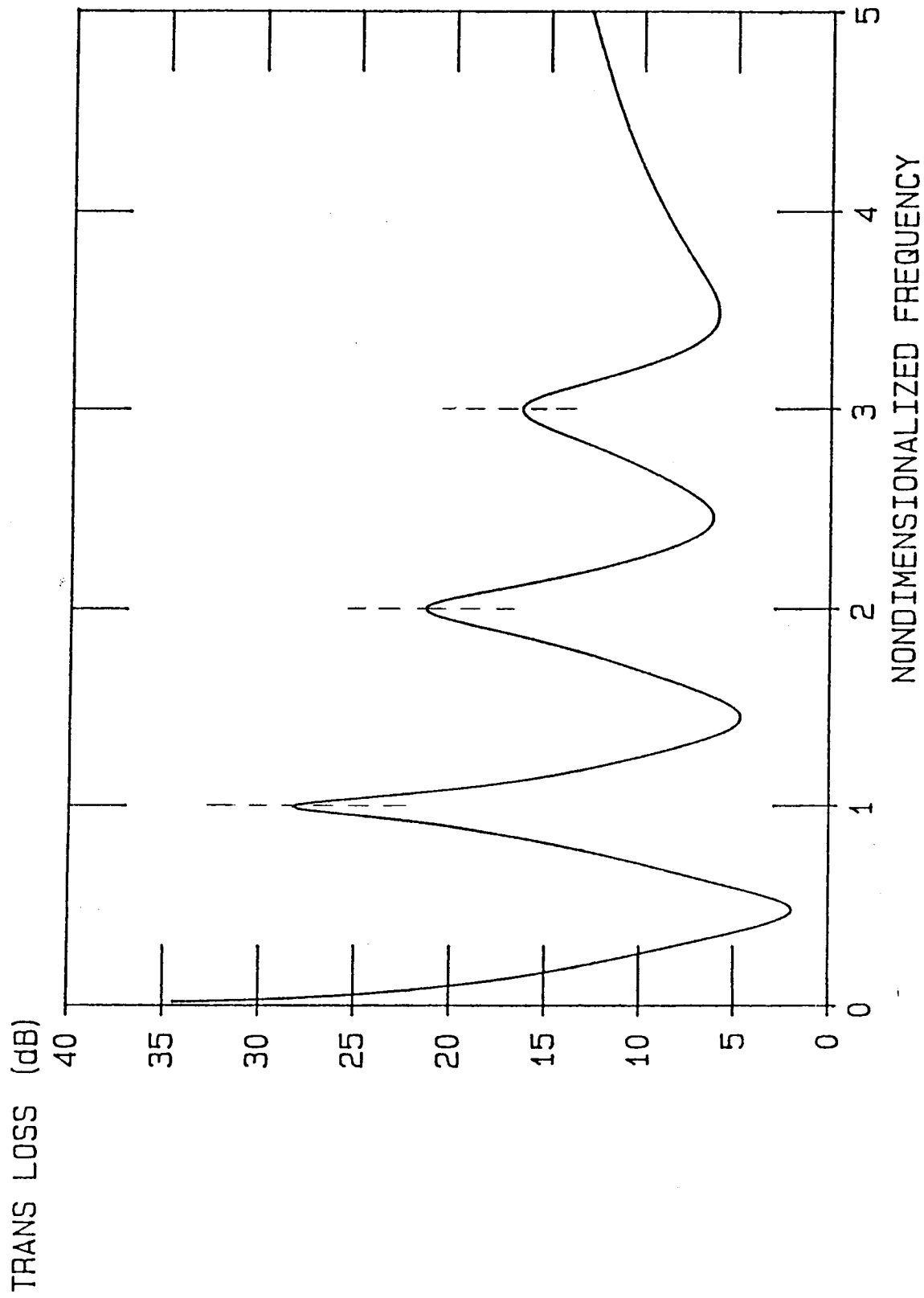
TRANS LOSS (dB)

Figure 1b: Four panel model with adjusted mass ratios to achieve correct attenuation frequencies. System damping set to zeta = 0.05.

apparatus with the panel theoretical model using precise values for panel stiffness, mass and damping. Figure 2 shows an apparatus which is being used to isolate an experimental ART panel (a four inch passive audio speaker with adjusted suspension and cone mass) far away from any interfering surfaces. The voice coil EMF generated by the speakers is conveniently used as a monitoring signal. By measuring the change in resonant frequency of the audio speaker (as a result of addition of a known mass), the true mass of the speaker cone (and hence, the true mass of the experimental passive ART panel) may be determined. Since the panel is rigidly mounted far from any surfaces, the apparent mass of the panel (that is, the speaker cone mass plus the effective addition to the inertia of the panel by the fluid around it) may be calculated.[2] In a similar manner, the damping ratio is determined by measuring the panel's dynamic response to a step input. By judicious exclusion of the apparent mass in all calculations using the standard relationships, the actual panel (speaker) properties may be determined as though the panel were in a vacuum. This in turn will permit the use of these parameters in the theoretical analysis in the appropriate manner. This work is only partially complete at this time.

Section 2c Flexible Frame Modeling

Analytic effort has begun on a flexible frame model which is shown in Figure 3. This model will be used to determine the effect of a flexible frame member on the ART concept. It may be possible to use this coupled system to advantage in reducing the first few harmonics associated with the blade passage frequency. The frame flexibility and panel-to-panel coupling will change the way mass and stiffness must be applied to adjacent panels to achieve the ART effect. A similar panel modeling program will be developed to plot transmission losses and determine optimized mass ratios for this important case.

SECTION 3 EXPERIMENTAL WORK

Section 3a Falloff Measurements Away from the ART Panel Wall

In addition to transmission loss plots shown in the previous progress report, the effectiveness of the ART concept in the two panel duct configuration was verified experimentally with measurement of sound pressure levels as a function of distance away from the ART panel wall. Figure 4a shows the sound pressure level falloff in dB away from the sound source in the two panel duct at various frequencies. Note that this falloff is referenced to a constant interior sound pressure
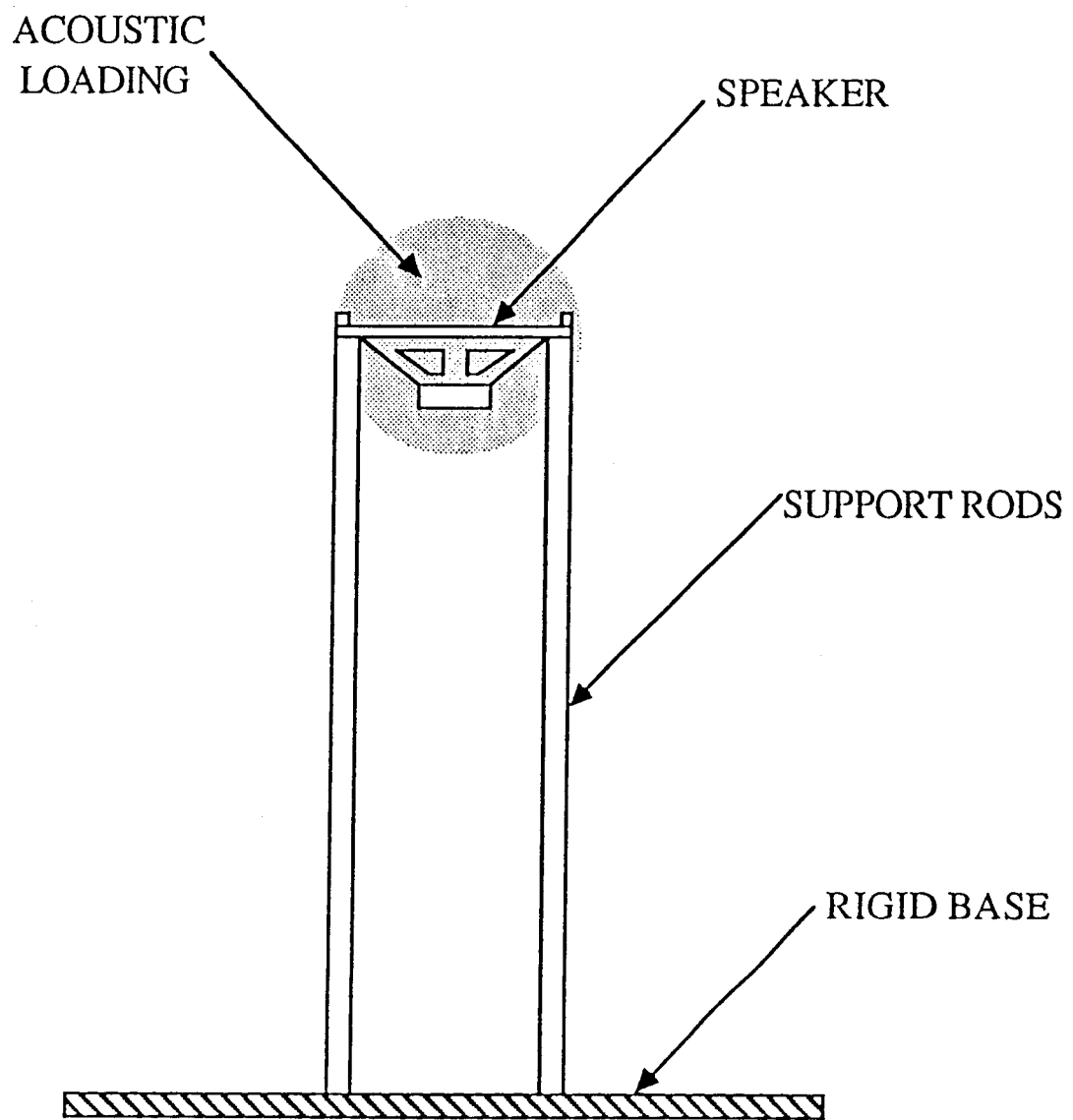
ACOUSTIC
LOADING

SPEAKER

SUPPORT RODS

RIGID BASE

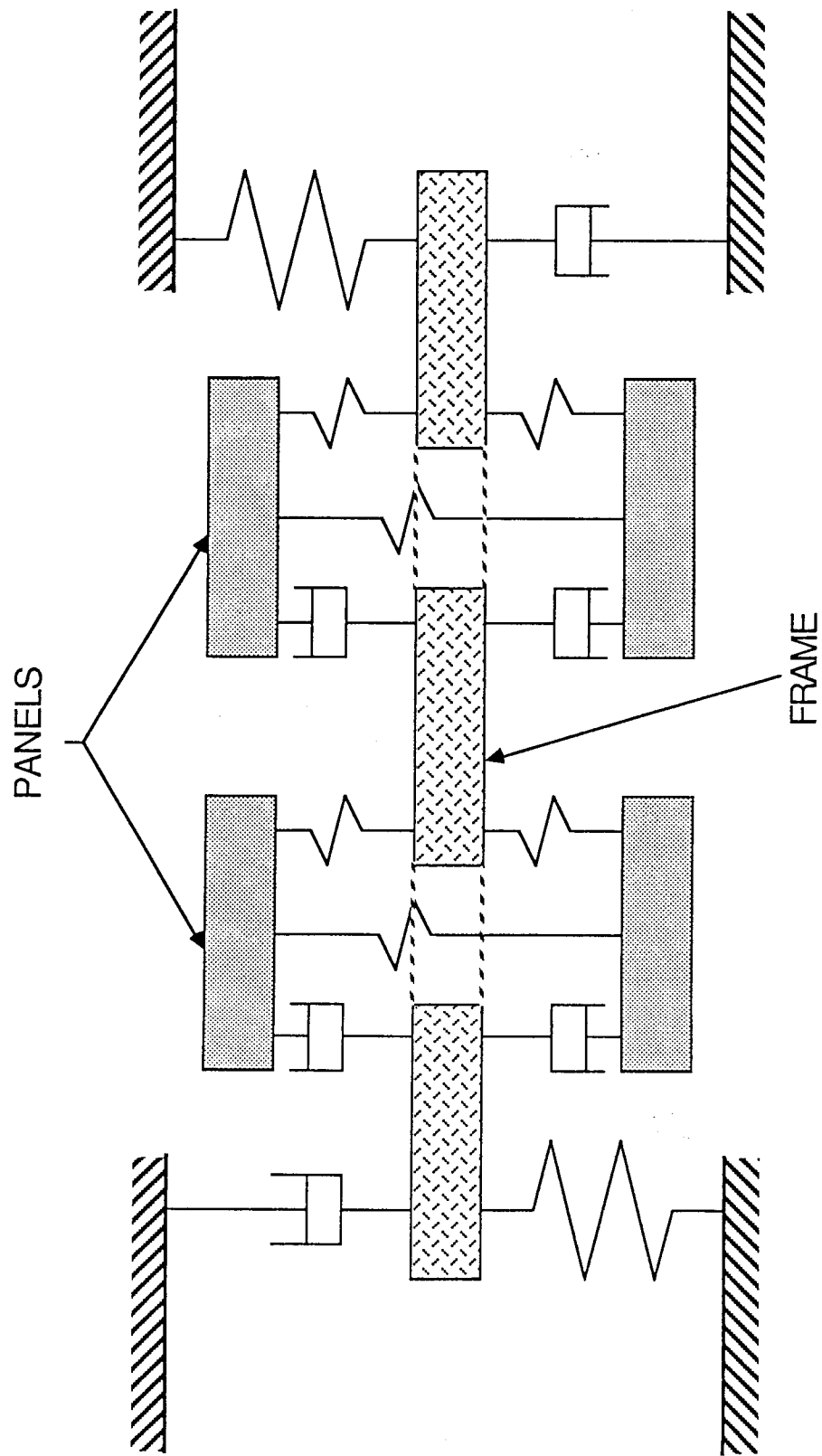Figure 2:   Test stand to measure ART panel parameters.

PANELS

FRAME

Figure 3: Flexible Frame Model

level at the ART panel array. The configuration here included two ART panels with resonant frequencies of 100 and 300 hertz. Because of these latter resonances, the falloff in dB at these frequencies is fairly low. However, at the design frequency of 200 hertz, a qualitatively exponential falloff as a function of distance away from the sound source is observed. This is a true indication of the cutoff effect provided by the ART concept. In a similar manner, Figure 4b shows the transmission loss across the ART panels as a function of distance away from the sound source. This figure indicates the drop in sound pressure level across the ART panel array, or in effect across the simulated aircraft fuselage wall. Again at the design frequency of 200 hertz, transmission losses of greater than 20 dB are realized for practical distances away from the ART wall. Neighboring frequencies show a reduced but nonetheless present transmission loss as well. The latter measurement is also an indication of the effectiveness of the ART concept as a function of bandwidth.

SECTION 4. FUTURE EFFORT

Section 4a Upcoming Analytical and Experimental Effort

Analytical effort will be focused in a number of directions for the first half of 1988. The proposed tasks for this next half-year effort are listed below.

-Continued work on model problems. Primary issues to be addressed with simple panel dynamics models include the effect of a non-uniform propagating pressure field acting on the exterior panel wall, and the modeling of the aircraft interior fuselage as a finite enclosure.

-Continued theoretical work on the general formulation of the problem. This formulation will consider a modal representation of the interior acoustic field coupled to a general modal representation of the wall motion.

-Continued exploration of innovative extensions to the ART concept. One such concept is the multiple panel block that allows for ART cancellations at several frequencies. Another concept involves higher order panel systems utilizing sets of coupled panels to achieve more effective acoustic cancellation and/or provide for more multiple cancellations.
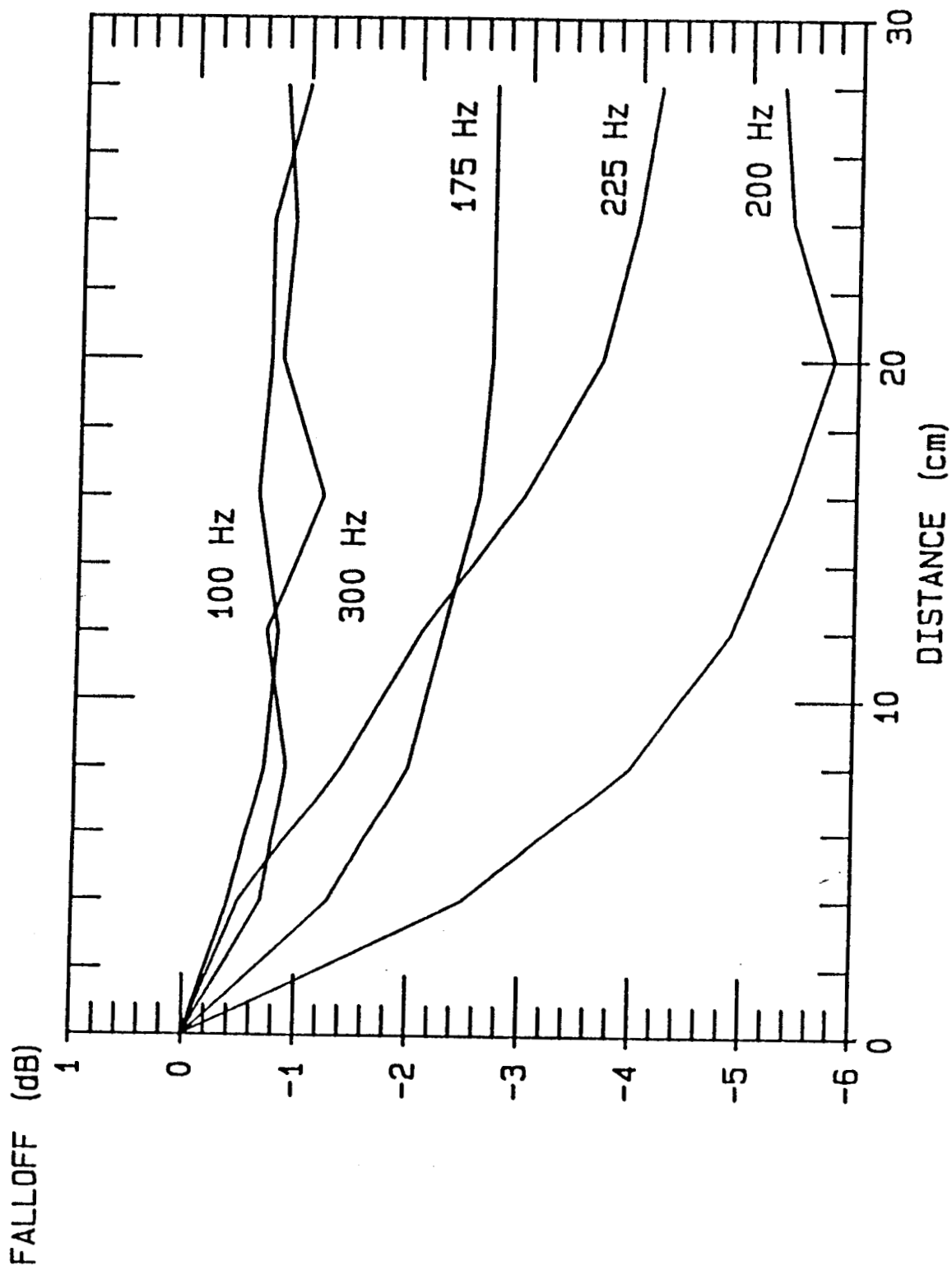
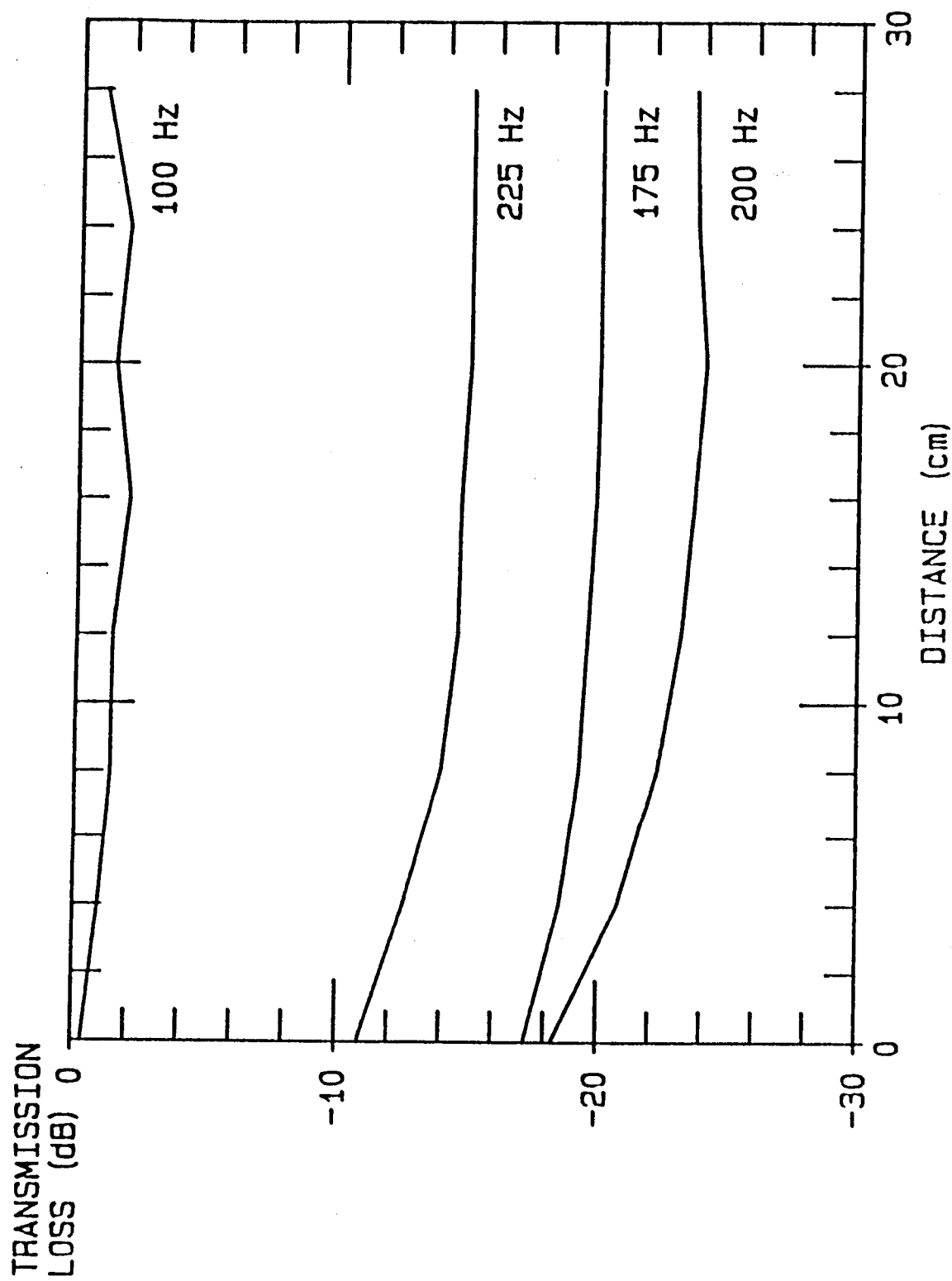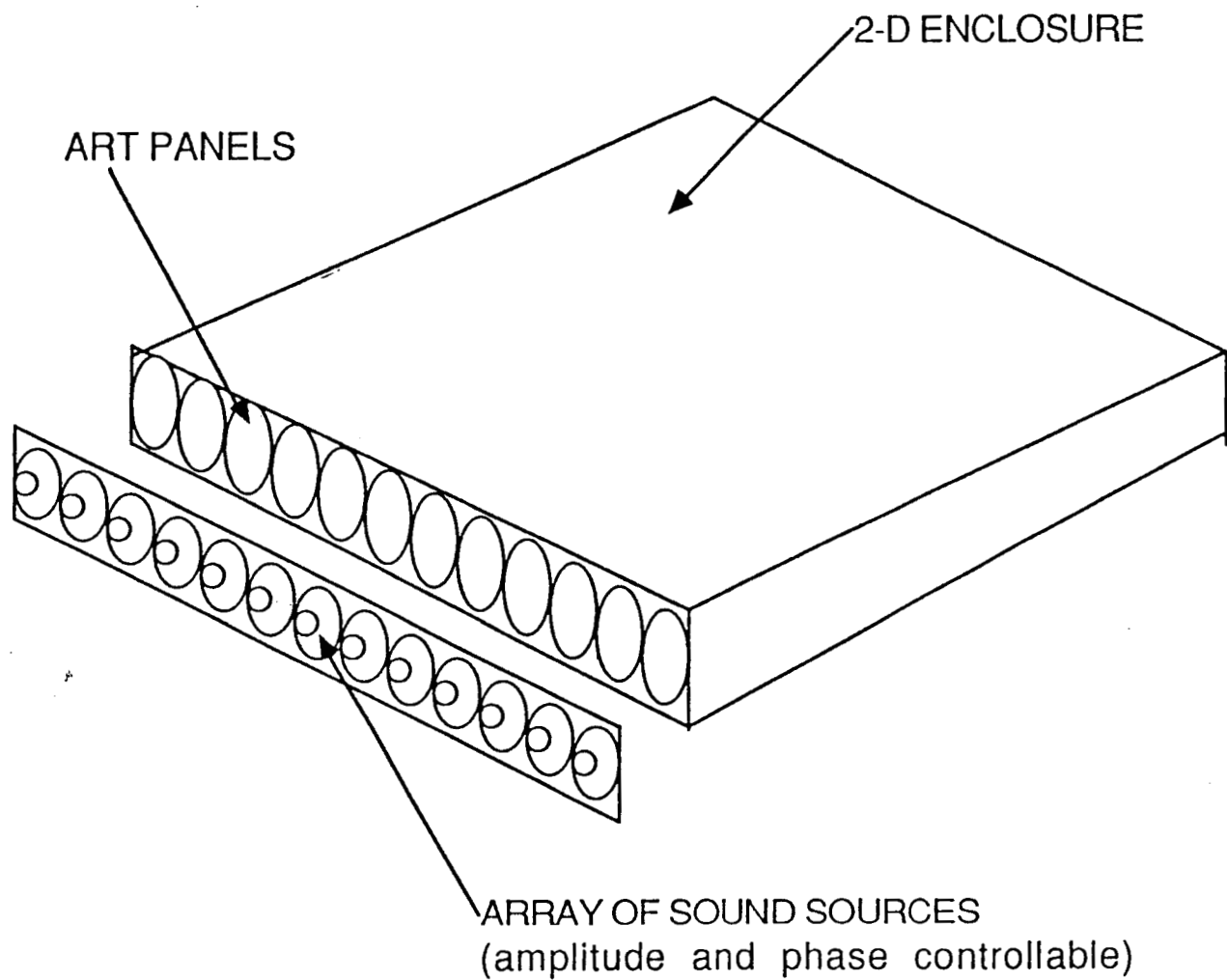Figure 4a: Sound pressure level falloff in dB referenced to the interior wall level sound pressure level.

Figure 4b: Transmission loss across ART panels as a function of distance away from sound source.

-Continued laboratory experiments. Set up and use the new data acquisition and processing system. Continued experiments on idealized panel configurations. One such configuration is shown schematically in Figure 5. This configuration allows for two dimensional acoustic modes in the enclosure, rather than simply just the one dimensional modes as in the previous experimental work. This latter setup will allow the ART concept to be studied under more realistic circumstances. By appropriate phasing of the multiple speaker sound source, a propagating incident field of the type produced by propellers can be simulated, and the performance of the ART panels then can be assessed.

Allows   simulation of realistic modal behavior.

Effect of nonuniform incident fields can be studied.

Effect of travelling incident fields can be studied.

Figure 5:   Experimental apparatus for second year effort.

REFERENCES

1. Bliss, D.B., Gottwald, J., and Bryce, J., "Interior Noise Reduction by Alternate Resonance Tuning- Six Month Progress Report," submitted to the Structural Acoustics Branch, NASA Langley Research Center, August 1987.

2. Lamb, H., **Hydrodynamics**. New York: Dover Publications, 1945, p. 139.

PAPER IN PROGRESS

Bliss, D. B., and Gottwald, J. A., "Aircraft Interior Noise Reduction by Alternate Resonance Tuning."